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Biomedical data were collected during high-G portions of 11 YF-16 test flights. Test pilots monitored revealed increased respiratory rate and volume, decreased tidal volume, and increased heart rate at higher G levels, with one pilot exhibiting various cardiac arrhythmias. Anti-G suit inflation and pressurization lags varied inversely with G-onset rate, and suit pressurization slope was near the design value.

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Aerospace Physiologist Communication

Physiologic and Anti-G Suit Performance Data From YF-16 Flight Tests

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Biomedical data were collected during high-G portions of 11 YF-16 test flights. Test pilots monitored revealed increased respiratory rate and volume, decreased tidal volume, and increased heart rate at higher G levels, with one pilot exhibiting various cardiac arrhythmias. Anti-G suit inflation and pressurization lags varied inversely with G-onset rate, and suit pressurization slope was near the design value.

AT EDWARDS AFB in September and October, 1974, 92 separate maneuvers during 11 test flights of the YF-16 were monitored by investigators from USAFSAM and NASA Flight Research Center, using the NASA inflight biological data acquisition system (1). From tape recordings of the four test pilots' ECG and respiratory flow, anti-G suit pressure, and aircraft G loading, the following measurements were determined: heart rate and rhythm, respiratory rate, tidal volume, minute respiratory volume, anti-G suit inflation-onset lag, suit pressurization lag and slope, and aircraft G-onset rate. The physiologic measurements were stratified by G level at which they were measured (to the nearest odd-numbered G level) and statistical comparisons were made in an attempt to discern G-related changes, even though the G-stress exposures were by no means equally distributed to the four test pilots. Anti-G suit inflation-lag data were stratified by G-onset rate.

The research reported in this paper was conducted by personnel of the Environmental Sciences Division, USAF School of Aerospace Medicine, and the Man/Systems Integration Division, NASA Flight Research Center.

Although G stresses as high as 7 G sustained for 1 min were recorded, relatively few ECG abnormalities were observed during the maneuvers. All of the cardiac arrhythmias (8 atrial, 3 junctional, and 2 ventricular premature beats) occurred in one pilot during three different flights, at G levels ranging from 3 to 7 G. During the 7-G, 1-min maneuver, only a minimal amount of T-wave flattening could be observed. Mean heart rate increased from 94 beats/min at 1 G to 138 at 7 G (Table I). Mean tidal volume progressively decreased from 900 ml at 1 G to 845, 725, and 655 ml at 3, 5, and 7 G, while mean respiratory rate increased from 18.9 to 25.4, 30.6, and 31.2 breaths/min at the same respective G levels. Measured independently from tidal volume or respiratory rate, mean respiratory volume

Fig. 1. Air Force 01568 — YF-16 used in this study. Photo courtesy of General Dynamics.

TABLE I. PHYSIOLOGIC MEASUREMENTS AT VARIOUS G LEVELS DURING YF-16 FLIGHT TESTS, MEAN ± S.E.M. (NUMBER OF MEASUREMENTS).

G load	Heart rate (beats/min)	Tidal volume (ml)	Respiratory rate (breaths/min)	Minute respiratory volume (l/min)
1	94.0±1.9(60)	900±25(70)	18.9±0.6(64)	13.8±0.8(52)
3	100.8±4.2(16)	845±27(71)	25.4±1.0(38)	15.3±1.3(16)
5	129.9±4.4(23)	725±26(47)	30.6±0.8(40)	17.5±1.0(27)
7	138.4±2.4(28)	655±19(13)	31.2±1.5(18)	18.0±1.0(31)

TABLE II. ANTI-G SUIT PERFORMANCE DURING YF-16 FLIGHT TESTS, MEAN ± S.E.M. (NUMBER OF MEASUREMENTS).

G-onset rate (G/s)	Anti-G suit inflation lag (s)	Anti-G suit pressurization lag (s)	Anti-G suit pressurization slope (psi/G)
0.0–0.9	0.63±0.10(32)	0.43±0.04(88)	1.44±0.02(91)
1.0–1.4	0.21±0.04(21)		
1.5–1.9	0.25±0.04(24)		
2.0–2.9	0.13±0.05(8)		
≥3.0	0±0 (2)		

extrapolated to 1 min was 13.8, 15.3, 17.5, and 18.0 l/min at 1, 3, 5, and 7 G, respectively. In each case, when the above physiologic variables were grouped into low-G (1 and 3 G) and high-G (5 and 7 G) measurements, unpaired t-testing revealed differences between the groups that were significant at the $p < 0.001$ level.

The time between the first 2-G point and the first evidence of suit pressurization in each maneuver was measured and grouped according to G-onset rate at the 2-G point. When G-onset rates were below 1 G/s, the mean suit-inflation lag was 0.63 s (Table II). At higher onset rates the mean lag decreased, until at or above 3 G/s, no lag could be measured. (The highest G-onset rate measured, incidentally, was 4.4 G/s; maximum pitch control input was in effect at the time.) Statistical (unpaired t-test) comparisons between low G-onset (≤ 1.4 G/s) and high G-onset (≥ 1.5 G/s) measurements showed inflation-lag differences significant at the $p<0.001$ level. Also measured were the time intervals between easily recognized G peaks and corresponding anti-G suit pressurization peaks in each maneuver: by this method we found a mean suit-pressurization lag of 0.43 s. The mean pressurization slope was found to be 1.44 psi/G, which is close to the design value of 1.5 psi/G.

The data presented no surprises. The heart rates and ECG changes were about what we would expect on the basis of our experience with subjects on the USAFSAM Human Centrifuge undergoing similar levels of G stress (2). The reduction in tidal volume with increased G load is an anticipated result of elevation of the diaphragm by anti-G suit pressure on the abdominal contents, as well as a result of G-induced increase in inspiratory effort. The respiratory rate increased at the higher G levels, mainly as a result of the pilots' repetitive straining (L-1 and M-1 maneuvers) to withstand the higher G forces. It was interesting to find that an increase in minute volume did occur at the higher G levels since, with a pilot voluntarily controlling his respiration to perform a straining maneuver, a decrease in minute volume might occur despite both an increased metabolic demand and a tendency toward hypoxia resulting from G-induced pulmonary dysfunction. The various anti-G suit performance measurements served only to indicate that, although the suit/valve system presently in use is good, there may be some room for improvement with respect to system responsiveness.

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